NASA JOHNSON SPACE CENTER ORAL HISTORY PROJECT
EDITED ORAL HISTORY TRANSCRIPT

DONALD M. CURRY
INTERVIEWED BY JENNIFER ROSS-NAZZAL
HOUSTON, TEXAS – 16 APRIL 2014

ROSS-NAZZAL: Today is April 16, 2014. This interview with Don Curry is being conducted for the JSC Oral History Project. The interviewer is Jennifer Ross-Nazzal, assisted by Rebecca Wright. Thanks again for taking the morning to sit down and meet with us.

CURRY: Thank you.

ROSS-NAZZAL: We appreciate it. Tell us how you came to JSC in ’63.

CURRY: That’s kind of an interesting situation. I went to work for the Bettis Atomic Power Laboratory in Pittsburgh, Pennsylvania, where I worked on the first nuclear aircraft carrier, *Enterprise*. Also, when I went to work at Westinghouse, I was selected to go to what they called their Advanced Design School; they basically paid for my master’s degree at the Westinghouse Educational Center and the University of Pittsburgh. After about four years in Pittsburgh, with all the weather, the snow, et cetera, I wanted to move back to Houston—or I wanted to move back to the Southwest.

ROSS-NAZZAL: Are you from Houston?

CURRY: No, I'm from Oklahoma, but I wanted to move back to the Southwest. I saw that NASA was interviewing for a new Center in Houston, so I actually applied. I sent not a résumé, I sent a discussion question, because they were interviewing in Pittsburgh. I wasn't selected. They said I wasn't qualified, although I had a master's degree in mechanical engineering at the time. I still wanted to move back, so I looked around and I actually ended up working at the General Dynamics Corporation in Fort Worth [Texas], worked in their thermal physics branch. At the same time, several people from that branch were leaving to go to the Manned Spacecraft Center in Houston. One of my good friends I met in Fort Worth, I worked with him, and I decided I would like to go there, too, because I wanted to do work that NASA did.

Basically I had had a really big interest, based on my research for my master's degree, on old NASA/NACA [National Advisory Committee for Aeronautics] technical note publications. I thought this would be a great opportunity to do that and continue to do the kind of work that I was doing with General Dynamics. I contacted George Strouhal, who's deceased. He in turn got me in contact with a man by the name of [R.] Bryan Erb, who is still living here in Houston. Within a couple of weeks, I had an interview in Houston with Bryan Erb. After that interview, they hired me within about a month's time, which was unusual because at that time, there was a lot of paperwork, a lot of delays, and there were a lot of people being hired. I moved down here in '63, to go to work at the Manned Spacecraft Center.

ROSS-NAZZAL: You were hired to work on ablators?

CURRY: Actually, I was hired to work on the thermal protection system, but my first assignment, which is again interesting to me—when I was at General Dynamics, I was also doing a little bit of work on entry heating. We, at that time, thought that NASA probably had all of the ablation programs that they would ever want, which was a real surprise to me when I came down here because I did have some computer experience. That was my first job. Bryan Erb said, “I want you to develop an ablation program for the Manned Spacecraft Center,” and he put out a caveat on these, said, “I don’t want one that runs long.” Mathematic problems can be very long-running, so he wanted me to do a program that was fast and could be used for design purposes. Fortunately, I met another man here who had a mathematics background, and he introduced me to an algorithm, I’ll put it that way, in a mathematics book that would do that.

That’s what I did; I developed an ablation program. It was an implicit solution, which I think was one of the first implicit solutions in ablation. It was fast, and it’s still used today. It’s been modified, obviously, probably many, many times since that time. That was my first job, and that was over in the Franklin apartment buildings, when we were all scattered all over Houston. The computer work was done at the University of Houston Computing Center, at that time.

ROSS-NAZZAL: When did you finally move on-site?

CURRY: That’s a good question. We moved from Franklin to Ellington [Air Force Base], and were at Ellington, in the barracks, for a while. Building 13 was one of the first buildings opened, other than Building 1 Headquarters. It was early on, when the site was first opened. I remember one of the times, walking into Building 13 after it had rained, and we walked on wooden planks because we still hadn’t put the sidewalks in. It was pretty early.

ROSS-NAZZAL: Yes, that is fairly early. After you worked on that computer program, were you starting to work on testing ablators in different ways, besides computers?

CURRY: We were doing that as soon as the JSC Arc Facility was developed.

ROSS-NAZZAL: That was the original one?

CURRY: The original one, the 1.0-megawatt facility. According to Don's [Donald J. Tillian] history, it opened up in September of '63. We started some testing back as early as late '63, probably early '64.

ROSS-NAZZAL: Were you involved at all in using that facility?

CURRY: Yes, I was, sure.

ROSS-NAZZAL: Can you talk about that?

CURRY: It was a very interesting facility because it was small, and we could basically almost be out in the chamber and watch the tests go on. It was a 1-megawatt facility, and we did a lot of different material testing at the time. Shortly after that, I'm not sure exactly what the year was, but then we developed a bigger Arc Jet, the 1.5-megawatt facility.

ROSS-NAZZAL: Do you know the reasoning behind the need for a bigger facility? I find it interesting that you had a facility that you were using for Gemini and Apollo, but then there was a need, I guess.

CURRY: The 1-megawatt really wasn't big enough for Apollo. We really couldn't get the power we needed, we couldn't get the heating rates that we needed, couldn't get the pressures we needed, the enthalpy values we needed. Also, we needed to be able to test bigger test articles. Initially, we tested small test articles, on the order of 1 inch to 2 inches, but we wanted to go to higher-sized articles. To do that, you had to have more power; you have to have a bigger exit nozzle, so a lot of equipment had to be changed. At the same time, we changed from a Plasmadyne facility to the Aerotherm facility, which was another innovation.

ROSS-NAZZAL: Would you explain the difference?

CURRY: I really don't know the big difference between the two. Don would know that.

ROSS-NAZZAL: Who was put in charge of creating and designing that building? Do you recall some of the folks?

CURRY: Dave [David H.] Greenshields was the branch chief for the Arc Jet facility, so I'm sure he was the major person in charge of getting that building built, the 1-megawatt facility, and then actually the modifications after that, too, because he was the branch chief for many years, over the Arc Jet as well as over the thermal protection group.

ROSS-NAZZAL: Do you recall any interesting tests for Gemini or Apollo that stand out in your memory, since you said you were more of a user than on the other side, a test operator?

CURRY: Sure. Probably the most significant one was on Apollo. We were testing the Apollo material. When you do the test, you have to seal the back surface of the ablator against the sting arm—we call it the sting arm—we bonded it to an aluminum plate with an adhesive. The test article would maybe be two inches in diameter, or two inches thick, or four inches thick. On one test, we stuck it into the Arc Jet, and within seconds we destroyed the entire test article, which, as you might realize, would cause a little consternation among the people. Upon examination of, we realized that we didn't get a good seal back at the interface between the ablator and the carrier plate, or the aluminum backup structure, we call it. Because of that, we had a gas flow that just went right through it because the material was porous. It had a porosity to it, so the gas just went through it and just basically destroyed it. Pressure of the gas plus the internal pressure being lower, it just had a great flow.

ROSS-NAZZAL: Yikes. Yes, I'm sure a lot of people were quite scared, thinking, "We're going to send this to space? What will happen to the crew?"

CURRY: Right, why would this material fail all of a sudden?

ROSS-NAZZAL: Did things change over time, in terms of testing, from Mercury through Apollo? Were you using different ablative materials?

CURRY: Sure. You'd have to say things changed because we learned from each test, and we learned more how to build the test articles, design the test article, design of all of the instrumentation that we put in a test article, actual shapes. We changed from just basically flat-faced specimens to what we call iso-Qs. An iso-Q specimen gives you a uniform heating flux across the surface, so that was an innovation that we had. Different tests could require different types of test articles itself, going all the way from stagnation point testing to parallel flow tests. As we moved into the 10-megawatt facility, that allowed us to do flat-plate testing, which we couldn't do in the old facility, the old 1-megawatt facility. Now, with the new facility at 10 megawatts, higher power, more flow, more gas flow, we could test flat plates, we could test plates at an angle of attack, and we could test larger test articles.

ROSS-NAZZAL: That's a pretty significant change.

CURRY: Absolutely, yes.

ROSS-NAZZAL: Would you talk about how you prepared for these tests for Apollo? What sort of requirements were set by the facility for you?

CURRY: We had what's called test readiness reviews, and we would write a test request. In writing the test request, you would write exactly what test conditions you wanted. In other words, what pressure you would like to test at, what heat flux you would like to test at, or you could actually specify enthalpy. You couldn't specify all three, so you could specify two of the three. That's one thing.

The second thing is you would specify how you wanted the instrumentation, whether you wanted just a bond-line thermocouple; whether you wanted what we called in-depth thermocouples, how you wanted them put in. The actual installation of the thermocouple was important. We used what we called land-length type thermocouples, which are little 1-inch links across the central core of the ablator, as opposed to what we call a point thermocouple, because the land-length type thermocouple gave better test data, gave you better data on the temperatures. Design of the test articles was very important, and different materials required different types of geometries.

I think one of the things we tested early on, even in Apollo, was wood. Balsa wood, mahogany, walnut, different types of woods that you can just go out and cut. Wood's a very good ablator. My point is that you have to understand how the ablator works, and I think I mentioned in the video interview that an ablator is like a wood-burning log in a fireplace. You put wood in your fireplace, and you watch it burn. Let's say you stop the flame for one night and look at the log, and it's got a nice black layer on it, which we call a char layer. An ablator does the same thing, but it's more efficient than wood and it's lighter weight. There's a lot of similarities between wood-burning and ablation because it's basically the same process. When we have a fire in a forest, forest fires are ablation of the wood. The National Forest Service actually uses ablation theory to predict how forests will respond in a forest fire, believe it or not.

ROSS-NAZZAL: I would never have known that.

CURRY: No, people don't understand that, that's true.

ROSS-NAZZAL: Tell me, why were you testing wood? What other sort of everyday materials were you testing in the facilities?

CURRY: At the time, we were interested just in understanding how different materials perform. Wood is a good material to test and determine its performance; actually, cork, which is wood, is used on missile systems. Cork is a material that's used to protect the missile during its ascent phase of the trajectory. Of course, for the entry phase of the trajectory, they use another material, a higher density material. Cork is very lightweight and pretty weak, but also it has good properties for the environment that you want to test at.

That's the other thing: the materials are selected based on the environment in which they're going to be used. One of the parameters that's very important is temperature because each material has a temperature limit. You want a design to be as efficient as possible. So for example, that's why the Shuttle system had carbon, which is a very high-temperature material, and had the tiles, which were a little bit lower-temperature material, and then it had the blankets, which were even lower-temperature materials. In combination, all three of them gave you a very efficient thermal protection system, in terms of weight and performance. The Arc Jet does all that for you, lets you test all those different materials, so you can determine their performance.

ROSS-NAZZAL: When you would run a test during Apollo, were you also there watching the test being done?

CURRY: Absolutely. Actually, during Apollo, we could be standing in what I call not the control room, but they had another little room out by the actual Arc Jet chamber. For many years, we could stand out in that little room and actually watch the test, looking through the windows into the main chamber of the Arc facility. That changed when safety got involved, and they decided it was too much of a hazard for a human to be out there, in case of a major accident, I guess, or incident.

ROSS-NAZZAL: When the test was over, then what did you do? You went out, and you looked at it?

CURRY: First of all, we would watch the test, and when we actually moved into what I call the control room that we had, we could watch it on the cameras. If we saw something happening that was bad, we could terminate the test sooner than we had planned. Each test had a specific test time, but after the test, absolutely, we could go out. Once the chamber had cooled down and we had re-pressurized back up to atmospheric conditions, we could go out and look at the articles in the chamber. After hours, when they took the articles out, of course, we could look at them close-up. During the actual test, we could watch the temperature rise. We could look at the surface temperature, we could look at the internal temperatures from the thermocouples. There was a lot of things that you could do and were doing during the test.

ROSS-NAZZAL: If at some point during the test you thought, "This isn't what I'm looking for," you said you could stop?

CURRY: We did what we'd call an abort. Absolutely, we could say, "Terminate the test."

ROSS-NAZZAL: Then you started preparing for another test because you wanted a different temperature or you weren't seeing what you liked?

CURRY: Correct, or we could wait, and wait until after we looked at the test article to make sure that's what we wanted to do. Generally speaking, you're correct, we would just prepare another test article, maybe change the test conditions. We'd actually do that many times when we were trying to establish what we called failing temperatures. If you wanted to do a failing temperature test, then you'd take it up in temperature, in increments, until you get to the failing point. Then, as soon as it starts to fail, you terminate the test.

ROSS-NAZZAL: Who would make these test articles? Was that something the contractor provided?

CURRY: Generally speaking, the company that made the material or fabricated the material did supply the test articles, yes.

ROSS-NAZZAL: You would just tell them what dimensions you needed and the shape you wanted?

CURRY: Right, you would buy the test articles from a corporation like Avco Corporation, at the time, and we would buy them already instrumented, per our design, our requirements.

ROSS-NAZZAL: At some point, did you no longer need to test the ablators, since you had all of this wealth of knowledge from Mercury and Gemini, and once Apollo had flown 7 and 8? Was that enough, or did you still need to keep testing?

CURRY: With respect to Mercury, Gemini, and Apollo, as soon as we had test flights, then we didn't need to do additional Arc Jet testing, unless we had some kind of anomaly during the flight. Then, we'd do anomaly flight test data. With Apollo, we had four separate unmanned test flights. Two test flights that entered at what's called Earth-orbital speed, and two flights that were lunar return speeds. We had test data from those four test flights, and we had the Arc Jet test data so we could compare the flight data with the Arc Jet data. We could also conduct post-test examination of the different flight materials actually taken from the flight cores with the Arc Jet cores. We had a way to compare actual ground testing with flight testing.

ROSS-NAZZAL: Were they very similar?

CURRY: Generally, the Arc Jet is a little more severe than the flight test, for certain types of materials, because the Arc Jet, we always had what we called a disassociated flow. The gas was not oxygen O_2, and it wasn't nitrogen N_2. It had been broken down into atomic oxygen and atomic nitrogen. Even at certain conditions for Apollo, we had some ionization. We tested at high enough temperature to ionize the gas. Generally flight conditions were pretty much the same but there's a difference between the flight and the Arc Jet, so they're not exactly 1:1. You would like them to be, but they're not.

ROSS-NAZZAL: I assumed that it was.

CURRY: No, they're not. Generally Arc Jet testing is more severe than flight, unless you cannot test at the flight conditions. There are conditions that you can't test at.

ROSS-NAZZAL: Can you give some examples?

CURRY: When the pressure's really high and the heat flux is fairly high, some Arc Jets can't reach both conditions at the same time. The high heating rate plus the high pressure, or you might even have a low heating rate condition and a high pressure. Sometimes you can't match it up exactly, so you do the best you can. Then you use your analysis to extrapolate the data you like, to go ahead with the design.

ROSS-NAZZAL: During the Apollo program, lots of guys have talked about how they were working nonstop, seven days a week, they were constantly on travel. Was that the same for you?

CURRY: I wasn't on travel because when I was working on Apollo, I worked in the analytical groups. Yes, we worked a lot of times on the weekends. One of the biggest jobs we had, after we got into the Apollo program, was the development of what we call the entry corridor. During the entry process, it's hard for people to understand this, but when you're at the Moon and you look back at the Earth, you have approximately a 1-degree angle entry corridor. Think about 1-degrees. At the distance from the Moon to the Earth, that distance of 1 degree is a huge distance.

Because of that, the entry corridor was extremely important. You can come in what we call too steep on the entry corridor and burn up because you're coming at too high a velocity, you're hitting the atmosphere, and the heating rate's going way beyond what you had designed for. Or, the alternate is you can come in too shallow and hit the upper limit of the entry corridor or get above it, and you skip out. Once you skip out, that's the end of it, you're into endless orbit; you can't come back.

Being able to hit that corridor was extremely important, and as a result of that, a lot of work with Apollo, once we had gotten the ablator material, the AVCO material, and had designed it, was to develop an entry corridor for MOD (Mission Operations Directorate). At the time we were doing this on our computer program. Off one single run, we got one data point. Many times we ran program runs overnight with priority. Many days, I remember picking up a huge stack of a computer output, maybe 20 or 30 runs, and we'd get 30 points or 20 points. From that data, we could develop a plot of the heating and of temperatures to give to the MOD people to help develop the corridor with respect to the entry flight angle and the flight conditions and so forth. A lot of that was done at night, and a lot of it was done over the weekends.

As you said, I think most people that worked on the Apollo program out here worked for no extra pay because we were too interested in it. It was too much of a challenge because there wasn't anything known. When [President John F.] Kennedy said, "We're going to the Moon," well, we didn't even have the material. We didn't have the guidance schemes. We'd never done some of these things. We'd only flown one Mercury flight, in fact.

ROSS-NAZZAL: Do you remember Apollo 11?

CURRY: Absolutely.

ROSS-NAZZAL: Where were you?

CURRY: Apollo 11, I think I was probably at home. Like I said, I wasn't part of the project management, so I wasn't really involved in Apollo 11 that much.

ROSS-NAZZAL: When did you start working on Shuttle?

CURRY: Nineteen-seventy, I became the subsystem manager on the Space Shuttle Orbiter leading edge structural subsystem, which is the nose cap, wing leading edge panels, arrowhead plate, and eventually, what we call the RCC [Reinforced Carbon-Carbon] chin panel.

ROSS-NAZZAL: What lessons did you learn from Apollo that you could transfer to Shuttle? It's two very different vehicles, of course.

CURRY: That's true, except for one thing. I think the reason I got selected to be the Shuttle leading edge manager for the carbon system was because the carbon system was an ablator.

ROSS-NAZZAL: It is?

CURRY: Yes, carbon ablates. I had experience in ablation and in the chemistry aspects of that. We had to develop computer programs to predict the carbon response, thermally. I think because of that experience I had on Apollo, it just moved me into the carbon system. I guess again, another way to say it is your fireplace log—when it forms that carbon layer, it continues to burn. That carbon layer goes away because it oxidizes away from the oxygen in the atmosphere. That's an ablation problem. I think that's probably why I got selected to be the initial subsystem manager on the leading edge structural subsystem.

ROSS-NAZZAL: In the beginning, they were probably looking at a whole host of ideas. What were some of the ideas that were thrown out for the system itself?

CURRY: For the Shuttle? Actually, we studied an ablative leading edge. That was one system. There were a couple of different contractors on carbon. One was McDonnell Douglas, and the other one was actually Chance Vought, at the time. From the competition, the Chance Vought people won the contract. Of course, they were a subcontractor to Rockwell at the time. Ablators would have worked fine, except that they were one-use only. You had to replace the ablator every time, and that was costly. It easily would have worked.

ROSS-NAZZAL: When did NASA settle on the RCC system?

CURRY: You had these phase II contracts, I'm not exactly sure, but maybe mid-1970s. I guess we had already decided because when I became subsystem manager in 1970, we'd already picked the system, basically, and already pretty much picked the Vought Corporation, with Rockwell.

ROSS-NAZZAL: You guys were testing those materials out at the Arc Jet, as well?

CURRY: Absolutely. I probably had more test hours at that Arc Jet on carbon testing than any other person that's ever used the Arc Jet, yes.

ROSS-NAZZAL: How many tests do you think that you've done out there.

CURRY: Three or four thousand, easily.

ROSS-NAZZAL: That's quite a few.

CURRY: Yes, and they were long-term tests because we were trying to establish the actual oxidation rates of the carbon system. The Arc Jet allowed us to find a lot of interesting things that we didn't really know about the carbon system that was selected. The carbon system on the Shuttle has a coating on it; a silicon-carbide coating protects the carbon substrate. That's what gives you the re-use temperature capability. Early on in the program, from tests done both at JSC and at Ames Research Center [Moffett Field, California], we uncovered what we called subsurface oxidation. Subsurface oxidation occurred because there were cracks that occurred naturally in the silicon-carbide coating. Those cracks allowed oxygen to penetrate or diffuse through the cracks down to the basic carbon. We were finding little pinholes underneath the carbon interface with the silicon-carbide coating.

The silicon-carbide coating depended upon—because it had been formed from the basic carbon substrate—that adhesion to hold the coating on. We had to develop how much oxidation we could have before we would have to replace the part. At the same time, we didn't want even that, so we developed new systems to infiltrate the carbon. One of them was a material called TEOS, tetraethyl orthosilicate, which actually infiltrated the carbon, which helped provide oxidation protection from this so-called pest oxidation or subsurface oxidation. Later on we determined that we still had some craze cracks on the exterior surface, so in order to seal those up, we developed a surface sealant. Arc Jet testing actually was instrumental in the development of all that and was instrumental in selecting how we did it, selecting the actual sealant material and how much TEOS we put in. Arc Jet testing was extremely important; in fact, it was the only way to do it.

As you know, Shuttle was never flight-tested in the sense of a unmanned flight test. The first test was with a man in it. I guess even the launch and landing tests were manned. That was different from Apollo. Apollo had four separate unmanned flights. We were depending and did depend upon the Arc Jet to give us the right data for these new materials because the carbon system was a new material, the tile system was a new material system, and the blankets were all new materials systems. The Arc Jet was used in all those materials systems.

ROSS-NAZZAL: That's pretty amazing.

CURRY: Yes, it is.

ROSS-NAZZAL: In the '70s, you were designing and developing this new system, but then as you began flying, you recognized that things had to be changed.

CURRY: Right, and also what happened in flying the Shuttle system, I'm not sure how many people know this, but the weight of the system went up. Because the weight of the system was up, that meant that the entry temperatures went up also. The initial carbon system was designed for a temperature of 2,750 degrees Fahrenheit. We actually learned from MPAD [Mission Planning and Analysis Division], new trajectories that they were flying indicated that we had to get to temperatures in excess of 2,900 degrees Fahrenheit. That caused two problems. First of all, the carbon system is a shell. Because it's a shell, it transmits the energy through the shell, and from top to bottom there's a temperature gradient on the lower surface of the shell to the top surface, which puts a thermal stress into the shell. Then, the carbon system was mechanically attached to the front spar with metallic links. Because of the higher entry temperatures and the higher air loads, we had to redesign the way we attached the carbon system to the wing spar. So we introduced what we call moment ties, which mechanically linked the top of the carbon to the bottom of the carbon. That was one thing.

Then, the second thing we had to do is prove through Arc Jet testing that the carbon system could, in fact, operate at a higher temperature than the original design. So, we had to test at higher temperatures, and eventually we tested and determined that the carbon system could easily be reused at an operational temperature of 2,900 degrees Fahrenheit. We established an upper-limit temperature, what we called the failing temperature, at 3,250 degrees Fahrenheit. With those two limits, then we analyzed practically every single MOD trajectory. We looked at all of the flight trajectories, the limits, to make sure that they stayed within the operational limits of the system, both structurally and thermally.

ROSS-NAZZAL: That was something I was going to ask you—you obviously helped to develop, design, and test the system in ’70s, but then we moved into operations. So you continually were testing this material. When there was a new mission and there was a new trajectory before they flew, you were continuing to analyze?

CURRY: We didn’t test, no. Once we established the limits, then all we did is evaluate the trajectory, took a look at the trajectory to make sure that by running it through our computer programs, we could determine the temperature that we were going to reach. We made sure that they stayed within that limit. That would be almost an endless task. So to help us, we developed what we called a simplified aeroheating analysis of the carbon system. We gave them, I’m going to call it a simple little computer program to run every time they ran their trajectories. That gave them a preview of the actual temperatures that they were going to get, so they could modify their trajectories before they actually made an operational trajectory. Once they made an operational trajectory, then we could check it with our more sophisticated programs. There was a lot of interaction between us and the mission operations group, and we spent a lot of time back and forth with them.

ROSS-NAZZAL: Were you ever called on during a mission, when they were looking at the vehicle and they were concerned something had been hit, prior to *Columbia*?

CURRY: I had never been called into the Mission Evaluation Room, the MER Room, except prior to the *Challenger* accident [STS-51L]. I got a phone call, I don’t know, I think it was, like 1:00 a.m. in the morning, that I needed to come in and look at the temperatures on the Shuttle system, from the carbon perspective. The carbon system can take low temperatures and had what we thought was good impact resistance, so I came in and looked at the temperatures and looked at the system. In conjunction with the subsystem manager out at Rockwell at the time, we determined that we could launch the system from the carbon perspective. Obviously, that turned out to be a bad decision from the solid rocket booster perspective. That was the first time I came in.

Then, of course, when we had the *Columbia* accident [STS-107], we were involved with evaluation of that. The group at the Structures and Mechanics Division, where I worked, we specifically requested inspection. It was turned down by the project management, but we didn't know where the foam had hit. As you know, we were turned down. Many of us felt like—and to this day, I feel like—had we known where the actual impact was, I feel like we could have fixed it sufficient to make the re-entry, not sufficient to re-use the vehicle, necessarily, but that we could probably have made through the entry cycle. We almost did, but we didn't quite make it. I think there was ways that we could have probably fixed it. Now, that's an opinion. Many people do not agree. It was a disaster that some of us feel like could have been avoided.

There's some other things about it, which again, are interesting to me. As the subsystem manager, at the time, on the carbon system, I guess it was prior to that flight, maybe one or two flights prior to the actual *Columbia* accident, they had had a piece of foam come off the size of the foam that hit the carbon system, but it hit some metal. I don't know where it hit, exactly. It must have hit on the solid rocket booster somewhere because they saw, on the post-inspections of some parts, that it had bent an aluminum part. The carbon system had been hit many times by foam. We could see it. It had been hit by little micrometeoroid impacts because we inspected for all this, after every flight. I, as a subsystem manager, had never been informed that we had had this huge piece of foam come off and hit the aluminum.

It's kind of like, in my mind, the *Challenger* accident; we knew about blow-by on those O-rings for many flights, but we didn't do anything about it. Here we've had damage on the tile system. If the tiles have been hit, we know the carbon's been hit, but we'd never seen any real damage on the carbon because it wasn't big enough, but had that one piece that came off that would have. If it can cause damage to metal, it can damage carbon, there's no question about it. I think that we didn't learn anything. Both accidents could have been prevented, but they weren't. Engineering tried their best, at least on *Columbia*, I feel like. That still haunts me, today, because it was my system, it was my panel nine or panel eight that got hit. Yet, I still feel like we could have fixed it enough, and it wouldn't have taken much.

ROSS-NAZZAL: What would have been the fix?

CURRY: First of all, we had to get an astronaut out there to do it, that's the first thing. That's a safety problem, I realize that, but we have on board all kinds of materials—blankets in the payload bay, rubber shoes that they wear, and things of this sort—that they could have filled up that hole to ablate those materials first. Because of that hole, we actually ingested gas temperatures probably on the order of 10,000 degrees Fahrenheit, maybe higher. No wonder it burned right through the aluminum front spar. It wasn't going to last long at those temperatures. Now, whether we could have done that or not, we'll never know.

ROSS-NAZZAL: I was going to ask if you had studied that because I came across an article that talked about how you and some other folks had studied, like in '99, 2000 sometime, the impact of a micrometeoroid or orbital debris on the reinforced carbon-carbon. I was curious about that.

CURRY: We had some damage levels on that, but they were small particles. We really never did do any real test of really large particles hitting the carbon system.

ROSS-NAZZAL: That's interesting.

CURRY: Yes, it's very interesting.

ROSS-NAZZAL: You were involved in the accident investigation?

CURRY: Absolutely, yes.

ROSS-NAZZAL: Will you talk about that, and how the Arc Jet played a role as well?

CURRY: Yes, sure. Of course, I went down to the reconstruction at the Cape [Canaveral, Florida], to see the parts and be a part of that investigation. Probably the main thing out of that accident was that, again, the Arc Jet turned out to be a very interesting facility to use, a major facility to use, in fact. The test data from the wing leading edge parts that they had picked up at the Cape, when they reconstructed it, the carbon parts had what's called a knife edge to them. In other words, they were shaped like the edge of a knife, going from thick to thin. That's the best way to say it, I guess, to you. We had done some tests in our damage assessments on the carbon system. Once we failed a coating, we let it go ahead and do some more damage. We could actually form a knife edge in a stagnation point test. The wing leading edge was not a stagnation point; it was what we called an angled flow test. We developed another system where we could test at an angle and a wedge. When we formed little damages, we actually were able to form a wedge test with a small damage, and then do an Arc Jet test.

When we examined the part after the test, we had a knife edge. It looked pretty much like what we saw on the *Columbia*. We actually were able to simulate it in the Arc Jet, and that was a request by the CAIB [*Columbia* Accident Investigation Board], for us to do those tests, to prove that we could halfway simulate what the entry's heating would do to the carbon system. I think we did do that. As a result of all of that, we developed what we call a damaged threshold. That was a big activity. We established exactly what size particle or what size damage in the coating we could have and re-enter safety, and which size that we could not have. Every single flight after that, we were in the MER, and we helped developed the inspection system that looked at the carbon, looked at the tiles, also, and we evaluated every single spot that we could see. As you know, we never did really find any major damage after that, but we looked at every single one.

One of the interesting things happened was that since we had developed these temperature limits for the carbon system, I don't know if you remember the incident where we had the gap filler sticking up, up near the nose cap area, right behind the nose cap, near the nose landing gear door? Aerothermal came up with heating on that, and they said that we are predicting temperatures that could indicate that the carbon's going to hit temperatures in excess of their failing mode, so we did a lot of analysis on that and actually made some presentations to the management council that met downstairs in Building 30. One of our recommendations to them was, "Right now, we can't tell you that we can enter safely if you leave that gap filler sticking up and the flow is tripped to a turbulent condition, like the Aerothermal group says it's going to be, so we recommend that we take it out." Several other people did, too, but that was our recommendation. Every flight, we spent hours over there. After the *Columbia* accident, we manned the MER almost 24 hours a day, definitely two-thirds of the 24 hours. We had real specific inspection techniques developed, inspection requirements that we had to adhere to.

ROSS-NAZZAL: Sounds like a big effort from your group.

CURRY: It was a big effort, yes.

ROSS-NAZZAL: What was the size that was small enough that you could enter?

CURRY: I'd have to go back to look at it. I'm thinking it was like, eighth of an inch? About an eighth of an inch damage in the coating.

ROSS-NAZZAL: Not much.

CURRY: No, not much, and of course, it was panel-dependent. Each panel had a little bit separate requirement, because the heating was different and environment was different.

ROSS-NAZZAL: You had tested each individual panel?

CURRY: We did a lot of testing at different damages in the coating to see how fast we could burn through, or if it would burn through the coating, to the substrate. We analyzed a lot of different test data. When that flight changes or something happened during the flight, we worked on additional calculations.

ROSS-NAZZAL: Were you ever doing any in-flight testing ever at the Arc Jet?

CURRY: We didn't have to actually do, as I recall, any real in-flight testing. The tile people had to do a lot of in-flight testing at the Arc Jet, but I can't remember us doing any really Arc Jet testing over there.

ROSS-NAZZAL: When you were doing all these, I guess, life cycle or impact tests, were you doing them all here at JSC, or were you also doing some at Ames?

CURRY: Everything was done at JSC. During the Shuttle program, we had Ames do some tests. Their test data did not agree with ours. In fact, their test data indicated we would have had failures. We would have a failure in a normal flight. Just for a normal entry, we would have exceeded some of our temperatures, had we used their test data. The only time we ever used any Ames data was when they helped find the subsurface oxidation, way back in the early '70s. For Shuttle, almost all of the carbon testing was done at JSC. I can't remember really going out to use Ames, because we just didn't get the same results. Our data seemed to match flight data because we had on-board measurements of temperatures, and so forth.

ROSS-NAZZAL: That says a lot about the JSC facility itself.

CURRY: Yes, it does. We've now closed it. Now we have one facility. I was on an NESC [NASA Engineering and Safety Center] board that studied the two facilities, and we found there's differences between them, and we couldn't resolve the differences. From the NESC report, which is restricted, we recommended a test program to be done between JSC and Ames to try to understand this problem. It was not approved. We've now closed the JSC facility, and we don't have the answer.

ROSS-NAZZAL: Tell me about that assignment. I wasn't aware of that study that was done. How did you get assigned to the board?

CURRY: I got assigned as a subject matter expert on ablative thermal protection systems and Arc Jet testing. I was what they call a national expert on ablatives, and the NESC hired me. I had retired, by the way, from NASA by then. I retired in 2007. I was a NASA expert, or an advisory expert, with that system. I think that came about because at that time, they were still trying to close the JSC facility, so the NESC did this study. We made these recommendations to the management of the NESC, we signed the report with them, they signed it, but the recommended Arc Jet testing was never implemented. Along with a lot of other people, like Don Tillian, we both have the same opinion about testing at Ames. We don't know what the data means—totally. It's good data, but what does it mean? Whether it is not correct, or is it correct? I don't know.

ROSS-NAZZAL: Yes, that's a shame.

CURRY: It is; it's a shame. The government destroyed a valuable resource. I spent two years writing letters to Congress on this, but to no avail.

ROSS-NAZZAL: I'm sorry to hear that.

CURRY: I am, too. The worst part about it is, for your information, the people at NASA Headquarters [Washington, DC] did not provide answers to some of the questions to the congressional people.

ROSS-NAZZAL: That's too bad.

CURRY: Yes, it is. It is too bad because my early years with NASA, I used to spend a lot of time at Ames on Arc Jet testing and ablation analysis. I spent weeks at Ames and at the Langley Research Center, both of them were really training grounds for me at the time. Those early scientists were really very smart.

ROSS-NAZZAL: Tell me a little bit about some of the advanced technology that you studied out at the Arc Jet. I saw you worked some on the X-38 and the Aeroassist Flight Experiment?

CURRY: I was the manager for the Aeroassist Flight Experiment. That was another really good project. The Aeroassist Flight Experiment was going to be taken up in the Shuttle Orbiter payload bay, and then we would re-enter the aerobraking experiment at a little over geosynchronous orbit speed. At geosynchronous orbit speed, we could get the temperatures up and the heat flux up, so that we had both the convective heating and radiative heating on the forward portion of the heat shield. That was mainly a tile system because we wanted it to be re-usable, and we didn't want any ablation products, because we wanted to have a pure re-entry environment. Ablation products will mess up the boundary layer and change the chemistry, so we didn't want to do that.

I was a manager on that, here at JSC. We actually built the aerobrake, and we were in the process of installing a tile system on it, which, at the time, was basically the Shuttle tile and blanket system, to deliver the aerobrake to Marshall Space Flight Center [Huntsville, Alabama]. They were the project management of it. It got canceled because of cost. The project management costs killed it, but we actually had built it here at JSC—in house. We bought the tiles from Lockheed, and we could install them ourselves. Our own technicians built the structure out in Building 9. It was wonderful. We had a great time on that.

ROSS-NAZZAL: But it never flew?

CURRY: It never flew. It would have provided data, aerothermodynamic data, for Mars entry that we were trying to get. It was the perfect experiment.

ROSS-NAZZAL: This was the precursor to what the Arc Jet had developed in terms of that CO_2 landing that Chris [Christopher B. Madden] and Steve [Steven V.] Del Papa talked a little bit about?

CURRY: CO_2, yes, that was for Mars entry. You need to have a CO_2 environment, so JSC developed the ability to test materials in a CO_2 environment.

ROSS-NAZZAL: What about the X-38? How different was its thermal protection system from Shuttle?

CURRY: Mainly the Germans provided the carbon system on X-38, the nose cap and the wing leading edge. Basically, all I did on X-38 was just monitor their work. I did some work on their seal system; we developed a seal system for the body flap area and did some work on that.

ROSS-NAZZAL: Were you are the Arc Jet for the final test that happened?

CURRY: Yes, I was.

ROSS-NAZZAL: Would you tell me about that moment and your memories about what happened?

CURRY: The final test that I was at was for Boeing. I work part-time for Boeing. Boeing is developing an ablator for their CCDev [Commercial Crew Development] capsule, which is their capsule to take men to the Space Station. We were doing the final set of ablation tests on the

Boeing material; we've been testing that material at different conditions of temperature and pressure to determine its performance. The last test was one of those tests. I can't really tell you much about the test, other than it was a Boeing material. It was sad to see. We got the test done fine, no problems, and got the data.

We're actually analyzing the data now, but to know we're sitting in that facility for the last time, that that'll be not there anymore is kind of sad, I guess. In some ways, angry. Like my wife said, "Well, Don, everything ends." That's true, it does, so let's end it. I feel sorry for the guys here at JSC.

ROSS-NAZZAL: Yes, they've lost a good resource.

CURRY: Yes, they have. Now, they've got to go to another place. One thing about our facility is that when the contractors came in to do the tests, we've always allowed them free access to the facility, been willing to make changes to the facility, arc test conditions, whatever. Plus, our costs have been about a factor of three less than Ames was. There's a big difference in our approach to testing and Ames's approach to testing.

ROSS-NAZZAL: I wanted to ask you, you mentioned that the test you were doing for Boeing, it's a Boeing material, but it's an ablator. I know it's probably proprietary, but is it similar to AVCO, or is it completely different from what was used during Apollo?

CURRY: It is different than Apollo material. It's hard for me to say it's similar to Apollo because it's a different material, it's a different-based material, but it has to operate at non-lunar conditions. It only has to operate at Earth-orbital conditions, which are significantly different than lunar conditions.

ROSS-NAZZAL: Have you run into any challenges, or were they similar challenges to the one you faced for testing of Apollo ablators?

CURRY: I don't think they're much different. We have to go through the same process, we have to get the data, we have to analyze the data, and determine if the material's going to work or not. We're in that process. It can meet all the design requirements, that's what I was trying to say.

ROSS-NAZZAL: Do you think, having worked on the Arc Jet for all these years, that testing has changed or anything changed over the years, since you started?

CURRY: Yes, we've become more efficient. We've been able to develop test article designs to meet certain requirements that we couldn't do before, initially. We understand a lot more now about the actual Arc Jet itself and its flow characteristics. Sure, we learned a lot. Remember, when we first started, back in '63, this was one of the first Arc Jets every built. From nothing to where we are, yes, sure, been a lot of our work done.

ROSS-NAZZAL: That was another question I wanted to ask. I know that there are other Arc Jets around the country. Langley [Research Center, Hampton, Virginia] has that small Arc Jet, and there's Ames, and I think Boeing has one. How was JSC's Arc Jet facility unique, when compared to all of these other facilities?

CURRY: One of the biggest differences is that we could run continuously, for hours, if we had to. When we were doing Shuttle testing on the carbon system, we used to test for one hour, continuously and at high temperature. Ames couldn't do that, and I'm not sure they can now. We could run long run-times. We could do low-heat flux cases, which some Arc Jets can't do, do testing at low-heat flux. That's important.

That's another thing about ablators: at low-heat flux, ablators don't necessarily perform as well as they do at high-heat flux. High-heat flux, you really get all the ablation process going, which is what you want. Low-heat flux, you get it going, but it's just a little bit different. Ablators can't be quite as efficient sometimes at the low-heat flux, but you have to test down there because you're going to go through that environment. Our facility could test low-heat flux, high-heat flux; it could test different size articles. Others can do that, too, but I think the biggest thing, at one time, was the ability for us just to test long times, continuous. Most facilities can't do that.

Like now, you're right, we have the Ames facility, which is the closest thing to the JSC facility—or the JSC facility is the closest things to the Ames facility, either way of saying it. The facility at St. Louis [Missouri], which is the Boeing facility, they can't test big test articles. They're limited in the size of the test article. You like to have a big enough test article that you can get a good representation of the heat flux and the way the material responds. The smaller the test article, the more, I guess, error you can have for performance. I'm not sure that they can test for long periods of time, and I'm not sure they can test some of the configurations that we can. The other facility that's available is the one at AEDC, Arnold Engineering [Development Center, Arnold Air Force Base, Tennessee], and their biggest problem is that their pressures are normally too high. They're a ballistic missile facility more than anything else. A lot of times, their pressures are too high to get the test conditions that you want for the entry conditions that we have, which are lower pressures, basically. So now we're down to Ames or AEDC. We can test there, you just got to realize what you're doing when you test there.

ROSS-NAZZAL: As you were leaving, or maybe you were discussing this with your colleagues, did you mention that you did a test for the Russians out at the Arc Jet, at one point?

CURRY: We did.

ROSS-NAZZAL: Can you share that?

CURRY: No. I can't share it because I don't have any of the data. We did the test—and Tillian knows more about this than I do—there was a test report written on the response of their material. It was secret, and it went to our division office, who kept it locked up for a while. Then, they transferred it to NASA Headquarters.

ROSS-NAZZAL: This was a test for Soyuz? Or you're not sure what it was?

CURRY: It was the ablation material for Soyuz. I don't think they've changed. That was a long time ago, and people ask for those results. They may exist, but I don't know where they are.

ROSS-NAZZAL: Was this before ISS [International Space Station] or after?

CURRY: No, way before. We tested this during the Apollo program.

ROSS-NAZZAL: Now I see why it was locked up. I wondered if you could talk about the camaraderie out at the Arc Jet over the years, since you worked it for so long.

CURRY: It was wonderful. Everybody was dedicated to that facility, first of all, and when you asked them to do something or wanted to be out there, they were very open to helping you design the test articles. A man by the name of Jim [James] Milhoan, who works out there, designed several test articles that helped us tremendously on the carbon system, particularly on our damage assessment analysis of the carbon. Developed a whole other system that allowed us to actually simulate a cavity behind the carbon system, so that once we actually burned through the carbon, we could exhaust that gas out and let the carbon continue to burn. That's how we're able to form these so-called knife edges. They've been extremely cooperative. There was a great respect between the engineering group, where I worked, and the Arc Jet group. We were the same group, as far as I was concerned. There was no difference, we all worked together. I can't remember us every having any problems at all, of any kind.

ROSS-NAZZAL: What significance do you think the Arc Jet has had, in terms of human spaceflight?

CURRY: I think without the JSC Arc Jet, we wouldn't have flown the Shuttle the way we did. We may have flown it, but not the way we did fly it. During Apollo era, that's another interesting story, we had a lot of Arc Jets. There were Arc Jets out at Boeing, there were Arc Jets at General Electric in Philadelphia [Pennsylvania], at that time, Langley had a big Arc Jet, not a small, little Arc Jet facility, a big Arc Jet. Of course, Ames had theirs. A company called Aerotherm had Arc Jets. Plasmadyne had an Arc Jet. We had seven Arc Jets around the country during Apollo, so we were testing all over the country.

Apollo was so different from Shuttle, in the sense that during Apollo, because of the mandate to land a man on the Moon by the end of the century, funding was available to do all this. We had Arc Jets around the country, we could test at the same conditions, and we could check each other. We had really good crosschecks against each other, plus, at the time, Langley and Ames both had real active analytical groups, too. So we could crosscheck analysis with each other. That's what we've lost when we closed the JSC Arc Jet facility. We don't have a crosscheck now. We've gone from a lot of crosschecks during Apollo to a couple of cross-checks during Shuttle to no cross-checks.

ROSS-NAZZAL: That's a big loss.

CURRY: It is. If you reduce the Arc Jet facilities down to one, you don't have a crosscheck. There is no way to understand any potential errors in the tests, test results, or the test analysis. Now, let's say Orion launches. They eventually go to the Moon or they go to Mars, then have to analyze some conditions that they hadn't anticipated. Now, they've got to go back to the same facility that gave them the data that said the design was adequate. Where's the crosscheck? There isn't. That's a bad situation.

ROSS-NAZZAL: What has the Arc Jet Facility meant to you, over the years?

CURRY: I guess it's my career because I've used it during Apollo, started using it actually with Gemini, a little bit, Apollo, and all of Shuttle. I've done a lot of advanced technology work with the Arc Jet, developing new ablator materials. I used to have SBIR [Small Business Innovation Research] contracts. Had one with another company, and we developed a whole series of ablative materials beyond Apollo, which I thought were really good materials that could be used for other programs. I think some of them actually are being used. But it was an SBIR, so as you know, SBIRs are proprietary to the company, so that's where it stayed.

ROSS-NAZZAL: One thing I noticed when I was out doing research, you have a Ph.D. in engineering. Was the Arc Jet in any way related to your doctoral studies?

CURRY: No, not really, because my Ph.D. was related to my analytical work I did in ablation. I just extended it a little bit in a dimensional way, to study some effects of multi-dimensional mass flux and flow in a porous media. It extended some of the equations that I had done in ablation. It just worked out that way, but I actually didn't do any tests at the Arc Jet.

ROSS-NAZZAL: Were you working on that during Apollo?

CURRY: I actually got my Ph.D. degree in '70, so yes, I guess I was.

ROSS-NAZZAL: That's impressive.

CURRY: I'm sorry, end of Apollo, the start of Shuttle, in that interim period between the two. I got a full year's leave of absence to do my dissertation.

ROSS-NAZZAL: That's a nice perk.

CURRY: Yes, it was, it sure was, to go to school for free and get paid.

ROSS-NAZZAL: Yes, that doesn't happen every day, does it?

CURRY: It doesn't. We did that a long time here at JSC. We'd still be doing that. In fact, we used to offer University of Houston graduate courses in Building 13.

ROSS-NAZZAL: I've seen the memos; I guess now you go over to UHCL [University of Houston-Clear Lake].

CURRY: No I finished my courses at the University of Houston main campus and then applied for the year's leave of absence to do my dissertation, and I got it.

ROSS-NAZZAL: I know you brought some notes.

CURRY: No, they are not notes. These were Tillian's in case you wanted to ask.

ROSS-NAZZAL: I think that we have hit on the questions I had. I'm just taking a look. Is there anything else you think that we might want to talk about, in terms of the Arc Jet Facility, Shuttle, Apollo, advanced programs?

CURRY: No, I think we've hit on it pretty well. I guess my concern is that on these advanced programs—I was noticing this latest thing that the [NASA] Administrator put out for NASA, *Visions*, or whatever he called it, new projects. I just wonder how he's going to accomplish this with less facilities. I was on a NRC [National Research Council] team; we did a 20-year look at NASA [called] *Roadmaps* [*NASA Space Technology Roadmaps and Priorities*]. One of the things that our group came up with was a lack of test facilities; NASA seems to be closing down test facilities. How are we going to advance technology to do these missions if we don't have the test facilities to prove the concepts? There was a quote by an Air Force general, he said, "I'll take one wind tunnel test to 10,000 CFD [Computational Fluid Dynamics] solutions," because the wind tunnel test tells him exactly what he wants to know. CFD solutions tell him something, but they're analytical.

If the guy running the program doesn't know what he's doing or doesn't understand the grid, is the answer good or not? Generally, they are, but it's like anything else. Tests always validate what you're doing, or they don't validate it, one or the other, but at least you get an answer. I guess my biggest concern is for what's going to happen at NASA. We've done a lot of good, good work, in the medical field and communications and computer—you name it. NASA spin-offs have been fantastic. I'm wondering, when you shut down some of these things, how that's going to be affected, and how are you going to meet these goals? One facility in the country can't do all the testing. It can't do the Air Force testing, and it can't do non-Air Force testing, or military testing. There's just not that much time.

ROSS-NAZZAL: That's a good point.

CURRY: We made those points in this NESC report, here. That's what's so frustrating, to me. If it had been totally political, I can understand it, but this was totally from an engineering perspective and a scientific perspective.

ROSS-NAZZAL: Well, thank you so much for coming in today. I enjoyed it.

CURRY: Sure. I hope it was satisfactory. I don't know.

ROSS-NAZZAL: Absolutely.

[End of interview]